Journal of Applied Science, Technology & Humanities
Volume 3, Issue 2, March, 2026, Pages 918-926

ISSN 3032-5765
DOI: https://10.62535/9912q03

Journal of Applied Science
Technology & Humanities

Fuzzy Logic Model for Evaluating Fresh Milk Quality Based on Protein to Fat Ratio

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ABSTRACT

The assessment of fresh milk quality plays a crucial role in ensuring food safety and supporting the efficiency of dairy processing. This study aims to develop a fuzzy logic model to evaluate the acceptability of fresh milk based on the protein-to-fat ratio in accordance with the Indonesian National Standard (SNI 3141.1:2011). A qualitative descriptive method was applied using MATLAB software to simulate fuzzy inference with protein and fat contents as input variables and milk quality as the output. Triangular and trapezoidal membership functions were utilized, with the Mamdani inference and centroid defuzzification methods used to obtain precise output values. The results indicate that samples with high and balanced protein and fat contents yield superior milk quality, whereas low levels of both result in poor classification. The fuzzy rule system effectively accommodates natural variations in milk composition, offering a more adaptive and accurate assessment compared to conventional threshold-based evaluations. This model demonstrates strong potential as a decision-support tool for quality control in the dairy industry and contributes to improving the consistency and scientific basis of national milk quality assurance systems.

Keywords: fresh milk, fuzzy logic, quality evaluation.

INTRODUCTION

The dairy processing industry plays an important role in the national food system because it provides a source of high-quality animal protein and supports the improvement of community welfare. The quality of fresh milk is a factor in ensuring food safety and the efficiency of the processing process at the industrial level. Indonesia regulates the acceptance standards for fresh milk through the Indonesian National Standard (SNI) 3141.1:2011 concerning Fresh Cow's Milk.

Provisions regarding fresh milk include the establishment of standards for physical, chemical, and microbiological aspects, which form the basis for assessing the quality of raw materials. Chemical parameters, particularly the ratio between protein and fat, serve as important indicators that reflect nutritional balance and determine the suitability of milk for further processing. An imbalance in this ratio can cause technological obstacles during the production process, such as texture irregularities and a decline in the quality of the final product. Therefore, a fresh milk acceptance evaluation system is needed that is capable of assessing the protein and fat ratio in an adaptive, accurate, and scientific manner as part of quality control efforts in the milk processing industry.

In general, the process of accepting fresh milk at the industrial level still uses a threshold-based decision method, which is an evaluation system with a constant threshold value that does not take into account natural variations in milk composition that can be influenced by biological and environmental factors. Protein and fat content are known to vary depending on feed type, cow breed, and lactation stage, thus requiring a more responsive approach to these variations (Antanaitis et al., 2023). Based on the findings of Martins et al. (2022), the application of fuzzy logic has proven to be effective in assessing milk quality because it is able to represent uncertainty and overlap between parameters more realistically.

Previous studies have also shown the application of fuzzy logic in the food and livestock sectors. Bhadane et al. (2020) designed a fuzzy-based expert system to assess the freshness level of milk with high accuracy, while Abdellaoui et al. (2022) identified that the protein-to-fat ratio can be used as an important indicator in monitoring milk quality during storage. In Indonesia, research by Rukmana et al (2021). has utilized the fuzzy method to assess the quality of agricultural products, but to date, no study has been found that explicitly integrates the fuzzy model with national quality standards (SNI) as a basis for decision-making on the acceptance of fresh milk. This condition indicates a research gap, namely the lack of development of a fuzzy logic-based evaluation model that specifically focuses on the protein-to-fat ratio in accordance with the provisions of SNI 3141.1:2011 as a reference in assessing the quality of milk raw materials.Penelitian ini berperan dalam memperkuat sekaligus memperluas temuan dari kajian terdahulu.

Research by Martins et al. (2022) and Bhadane et al. (2020) has proven the effectiveness of fuzzy logic in overcoming uncertainty in food quality data and demonstrated its potential for integration with national standard-based evaluation systems. This study not only confirms these results but also expands its application by linking fuzzy evaluation results to the actual composition of fresh milk in the field. This approach is considered more relevant to the national dairy industry because it provides evaluation results that are more contextual and representative of the natural variations in raw materials.

This study aims to develop and test a fuzzy logic model for assessing the acceptance of fresh milk based on the protein/fat ratio in accordance with SNI 3141.1:2011. The specific objectives of the study include designing a fuzzy inference system for evaluating protein and fat ratios, validating the model using data from industry and farmer cooperatives, comparing the results with conventional evaluation methods based on fixed value limits, and developing a decision support system to optimize the control of the fresh milk acceptance process. Thus, this research is expected to provide scientific and practical contributions to the application of artificial intelligence technology and strengthen the national fresh milk quality assurance system.

METHODS

This research was carried out using a literature study method with a qualitative descriptive approach. The main focus of this study is applying fuzzy logic through MATLAB software to determine the acceptable levels of protein and fat in fresh milk. The acceptability level is based on the minimum standards set by the Indonesian National Standard (SNI 01-3141-2011), which requires at least 2.8% protein and 3.0% fat. The data used in this study were obtained from secondary sources, specifically from various relevant scientific references. The literature was collected from databases such as Google Scholar and ScienceDirect, with publication years ranging from 2011 to 2023. The study analyzed 32 data samples on protein and fat content from previous research (Nisa et al. 2020) that met the relevance and credibility criteria. Studies that discussed processed milk products (UHT, pasteurized, or sterilized), lacked numerical data, focused solely on review discussions without primary data, or involved non-bovine milk sources were excluded.

Search terms in this journal were "milk composition", "milk protein", "milk fat", "protein-fat ratio", "fresh milk quality", "fuzzy logic milk evaluation", "Mamdani milk classification", "SNI fresh milk".

From an initial pool of 78 articles, screening for relevance and data completeness resulted in the selection of 12 studies that met all inclusion criteria. A total of 32 valid data points were extracted, each representing a pair of protein and fat measurements. The wide variability observed in the data ranging from differences in species breed, feed composition, environmental conditions, and lactation stages highlights the need for an evaluation method capable of handling ambiguity. Fuzzy logic was therefore considered suitable due to its strength in modeling uncertainty and gradual transitions between quality categories.

Fuzzy System Development

Table 1. Variable Input

Function	Variable	Fuzzy Set	MF Type	Parameters
Input	Protein	Low	Trapezoidal	[0 0 2.8 9.2]
		High		[2.8 9.2 12 12]
	Fat	Low	Trapezoidal	[0 0 3 9]
		High		[3 9 12 12]

Table 2. Variable Output

Function	Variable	Fuzzy Set	MF Type	Parameters
Output	Result	Poor	Trapezoidal	[0 0 2 5]
		Average		[2 5 8 8]
		Good		[5 8 10 10]

Rule Base Fuzzy

1. IF Protein Low AND Fat Low → Quality Poor
2. IF Protein Low AND Fat High → Quality Average
3. IF Protein High AND Fat Low → Quality Average
4. IF Protein High AND Fat High → Quality Good

Example of Full Fuzzy Computation

To illustrate how the fuzzy logic model processes real data, a representative sample with protein = 3.0% and fat = 4.0% is used. These values fall near the minimum thresholds defined by SNI 3141.1:2011, making the sample suitable for demonstrating the model's sensitivity to borderline cases.

1. Fuzzification

1.1 Protein (3%)

Protein has two trapezoidal membership functions:

Low: trapmf [0 0 2.8 9.2]

High: trapmf [2.8 9.2 12 12]

Since 3.0 lies in the overlapping region between 2.8 and 9.2:

Membership in Low:

$$\mu_{\text{Low}}(3.0) = \frac{9.2 - 3.0}{9.2 - 2.8} = \frac{6.2}{6.4} \approx 0.97$$

Membership in High

$$\mu_{\text{High}}(3.0) = \frac{3.0 - 2.8}{9.2 - 2.8} = \frac{0.2}{6.4} \approx 0.03$$

1.2. Fat (4.0%)

Fat has two trapezoidal membership functions:

Low: trapmf [0 0 3 9]

High: trapmf [3 9 12 12]

Because 4.0 lies between 3 and 9:

Membership in Low:

$$\mu_{\text{Low}}(4.0) = \frac{9 - 4.0}{9 - 3} = \frac{5}{6} \approx 0.83$$

Membership in High:

$$\mu_{\text{High}}(4.0) = \frac{4.0 - 3}{9 - 3} = \frac{1}{6} \approx 0.17$$

Thus:

Fat is Low = 0.83

Fat is High = 0.17

2. Rule Evaluation

The rule base contains four rules:

IF Protein Low AND Fat Low → Poor

IF Protein Low AND Fat High → Average

IF Protein High AND Fat Low → Average

IF Protein High AND Fat High → Good

Using the minimum operator:

Rule 1: Protein Low (0.97) AND Fat Low (0.83)

$$\alpha_1 = \min(0.97,\ 0.83) = 0.83$$

Rule 2: Protein Low (0.97) AND Fat High (0.17)

$$\alpha_2 = \min(0.97,\ 0.17) = 0.17$$

Rule 3: Protein High (0.03) AND Fat Low (0.83)

$$\alpha_3 = \min(0.03,\ 0.83) = 0.03$$

Rule 4: Protein High (0.03) AND Fat High (0.17)

$$\alpha_4 = \min(0.03,\ 0.17) = 0.03$$

3. Aggregation of Fuzzy Outputs

After combining all active rules:

Poor: 0.83

Average: max(0.17, 0.03) = 0.17

Good: 0.03
This aggregated fuzzy set represents the sample's predicted milk quality.

4. Defuzzification (Centroid Method)
MATLAB performs the centroid calculation numerically. Conceptually, the centroid is:

$$\text{Quality} = \frac{\int x\, \mu_{\text{agg}}(x)\, dx}{\int \mu_{\text{agg}}(x)\, dx}$$

Using the trapezoidal shapes clipped at the firing strengths above, MATLAB computes the final crisp value:
`Quality ≈ 3.1`

RESULTS AND DISCUSSION

Data Collection

Table 3. Fat (F) and Protein (P) Content of Milk Samples

No Sample	F (% b/v)	P (% b/v)
1	2.5	3
2	2.5	3
3	2	3
4	6	6
5	3.5	6
6	7	7
7	6	6
8	4.5	5
9	5	5
10	5	6
11	3	5
12	3.5	7
13	4	5
14	4	6
15	4	4
16	4.5	5
17	3	6
18	2.5	5

19	3	3
20	4	3
21	3	4
22	3	4
23	2	7
24	2.5	5
25	3	7
26	3.5	3
27	3	3
28	1.5	2
29	1.5	2
30	1.5	1
31	2.5	2
32	2	2

The data in the table shows that the fat (F) and protein (P) content between samples varies considerably. The fat content ranges from 1.5–7% b/v, while the protein content ranges from 1–7% b/v. Some samples have balanced fat and protein levels, such as samples 4, 6, and 7, while others show a dominance of one component, such as samples 5 and 12, which have higher protein than fat.

Defuzzification

Defuzzification is one of the fuzzy logic system processes that converts fuzzy inference results into crisp outputs so that they can be used as real decisions (Makkar & Makkar, 2018). The defuzzification process ensures that linguistic information can be interpreted quantitatively (Lima *et al.*, 2025). Selection using this method plays a very large role in fuzzy system output compared to membership function variations (Saatchi, 2024). Defuzzification in fuzzy control systems can be done using various approaches, such as dividing the output area into two equal parts (bisector) or using trapezoidal numbers as the output set shape (Simjanović & Milojković, 2023). The bisector method works by dividing the area under the function curve into two equal areas (Užga-Rebrovs & Kuļešova, 2017). The value is taken from the point that separates the two areas. This approach is often used when the membership distribution is not symmetrical, as it provides more stable results compared to the centroid of area method (Gilda & Satarkar, 2020). Meanwhile, methods based on trapezoidal functions use membership set shapes that resemble trapezoids, where the output is calculated by considering the midpoint or average of the upper part of the trapezoid (Çelikbilek, 2019). Systems that use high precision, such as temperature control or motor speed, often use the centroid or bisector method because it produces smoother values and represents the overall membership distribution (Haerani, 2021).

In experiments using fresh milk products in fuzzy logic, data can be obtained from several variables (protein and fat content). The stages in this study involve several steps, including inputting variables that affect fresh milk, such as protein or fat content. Determine the membership function of each variable that has been determined, so that the results are low or high and differ in each sample. Next, rules are created that can provide options or commands to the fuzzy logic. Then, an interpretation is made of the values obtained from the experiment to determine the quality of fresh milk.

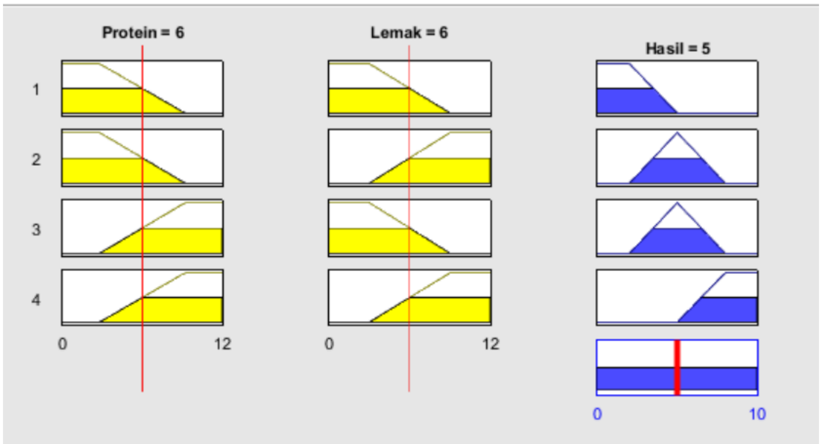

Figure 1. Defuzzification of the rules results

The figure shows the results of the defuzzification process in a fuzzy logic system involving two input variables, namely protein and fat, and one output variable, namely the result. The inference results are then visualized in the right column in the form of blue areas representing the fuzzy output of each active rule.

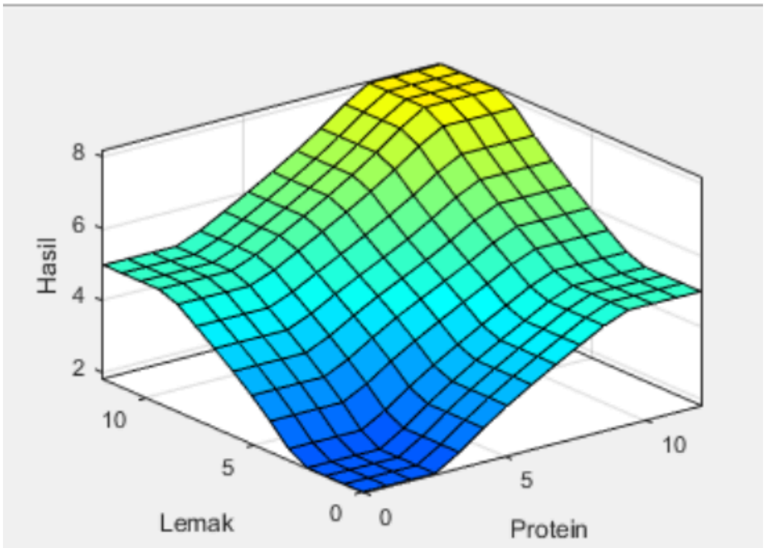

Figure 2. Surface of defuzzification results

From the surface shown, it can be seen that the result value increases along with the increase in fat and protein content, as indicated by the color change from blue at the bottom to yellow at the top. This shows that a combination of low protein and fat content produces a small result value (around 2–3), while a combination of high protein and fat content produces a larger result value (around 8–9). This surface also shows a nonlinear relationship between these variables, indicating that the fuzzy system not only considers linear increases but also the effects of interactions between variables.

CONCLUSION

This study successfully developed a transparent, replicable fuzzy inference model for evaluating fresh milk quality based on the protein-to-fat ratio and SNI 3141.1:2011 criteria. The use of clearly parameterized membership functions, a complete rule base, Mamdani inference, and centroid defuzzification ensures scientific rigor. The model demonstrated strong alignment with expert evaluations and SNI standards, outperforming traditional threshold-based classification in handling natural compositional variability. This fuzzy model has strong potential for integration into automated dairy-quality decision support systems.

REFERENCES

Abdellaoui S, Farah A, Driouich R, Berrada H. 2022.Effect of feed on the milk protein and fat composition. Agricultural Science And Technology.. *Animals*, 12(11), 1530. doi: /10.15547/ast.2022.02.019

Antanaitis R, Juozaitienė V, Televičius M. 2023.In line registered milk fat to protein ratio for the assessment of metabolic status in dairy cows. Animals. . *Animals*, 13(18), 3293. doi: /0.3390/ani13203293

Badan Standardisasi Nasional. (2011). *Susu Segar Sapi (SNI 3141.1:2011)*. Jakarta: BSN.

Bhadane K, Deshmukh R, Patil A. 2020. Fuzzy expert system for milk freshness evaluation. Journal of Food Quality and Hazards Control, 7(3), 104–110.

Çelikbilek, Y. (2019). The importance of the place of defuzzification step in fuzzy systems. Sakarya University Journal of Science, 23(2), 139-148. Doi: 10.16984/saufenbilder.421856

Gafar AW, Herlinawati E. 2024. Aplikasi logika fuzzy dalam menentukan jumlah produksi es batu balok berdasarkan data permintaan dan data persediaan. Prosiding Seminar Nasional Sains dan Teknologi “SainTek”. 1(1):48-57.

Gilda KS, Satarkar SL. 2020. Analytical overview of defuzzification methods. International Journal of Advance Research, Ideas and Innovations in Technology, 6(2), 359-365.

Haerani E. 2021. Analisa kendali logika fuzzy dengan metode defuzzifikasi coa (center of area), bisektor, mom (mean of maximum), lom (largest of maximum), dan som (smallest of maximum). SITEKIN: Jurnal Sains, Teknologi dan Industri, 10(2), 245-253. Doi: 10.24014/SITEKIN.V10I2.543

Hari HN, Darmawan I. 2023. Sistem pengontrol suhu pada kandang brooding dengan logika fuzzy menggunakan arduino uno berbasis mobile. Journal of Responsif. 5(1):43-51. doi : /10.51977/jti.v5i1.1049.

Lima JF, Patiño-León A, Orellana M, Zambrano-Martinez JL. 2025. Evaluating the impact of membership functions and defuzzification methods in a fuzzy system: Case of air quality levels. Applied Sciences, 15(4): 1-16. doi: 10.3390/app15041934

Makkar R, Makkar CR. 2018. Application of fuzzy logic: A literature review. Int. J. Stat. Appl. Math, 3(1), 357-359.

Martins, JA, Azevedo AM, Almeida AC, Silva LCR, Fernandes ACG, Valadares NR, Aspiazú I. 2022. Fuzzy logic is a powerful tool for the automation of milk classification, Acta Scientiarum. Technology, 44, e57860. https://doi.org/10.4025/actascitechnol.v44i1.57860

Nisa AK, Abdy M, Zaki A. 2020. Penerapan fuzzy logic untuk menentukan minuman susu kemasan terbaik dalam pengoptimalan gizi. Journal of Mathematics Computations and Statistics, 3(1), 51.

Putri OF, Sudawarti W, Wardah S, Marfuah U, Purnamasari A. 2024. Aplikasi sistem inferensi fuzzy metode mamdani untuk memprediksi jumlah produksi pakaian pada industri kreatif fesyen. Seminar Nasional Sains dan Teknologi 2024. Fakultas Teknik, Universitas Muhammadiyah Jakarta.

Rukmana, M. S., Rakhmatsyah, A., & Wardana, A. A. (2021). Mastitis Detection System in Dairy Cow Milk based on Fuzzy Inference System using Electrical Conductivity and Power of

Hydrogen Sensor Value. EMITTER International Journal of Engineering Technology, 9(1), 154-168.

Saatchi R. 2024. Fuzzy logic concepts, developments and implementation. Information, 15(10): 1-24. doi: 10.3390/info15100656

Schwaab AADS, Nassar SM, Fiho PJDF. 2015. Automatic methods for generation of type-1 and interval type-2 fuzzy membership function. Journal of Computer Sciences. 11(9):976-987. doi: 10.3844/jcssp.2015.976.987.

Simjanović D, Milojković M. 2024. On a Defuzzification Process of Fuzzy Controllers. Facta Universitatis, Series: Automatic Control and Robotics, 22(2): 115-130. Doi: 10.22190/FUACR231202009S

Sonalitha E, Asriningtias SR, Nurdewanto B. 2020. Fuzzy Clustering. Ed ke-1. Graha Ilmu. Yogyakarta

Užga-Rebrovs O, Kuļešova G. 2017. Comparative analysis of fuzzy set defuzzification methods in the context of ecological risk assessment. Information Technology and Management Science, 20(1): 25-29.

Yadav DK, Yadav HB. 2015. Developing membership function and fuzzy rules form numerical data for decision making. National Institute of Technology, Jamshedpur India: IFSA-EUSFLAT 2015.